Livestock Science 145 (2012) 205–211

Contents lists available at SciVerse ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Management targets for maximising the short-term herbage intake rate of cattle grazing in *Sorghum bicolor*

L. Fonseca [a,*], J.C. Mezzalira [a], C. Bremm [a], R.S.A. Filho [b], H.L. Gonda [c], P. C.de F. Carvalho [a]

[a] *Grazing Ecology Research Group, Federal University of Rio Grande do Sul, Porto Alegre, RS 91540-000, Brazil*
[b] *Santa Catarina State University, Lages, SC 88520-000, Brazil*
[c] *National University of Central State of Buenos Aires, Argentina*

ARTICLE INFO

Article history:
Received 22 June 2011
Received in revised form 31 January 2012
Accepted 1 February 2012

Keywords:
Canopy height
Grazing down
Sward structure

ABSTRACT

One of the variables in the structure of the sward with the most influence on the short-term herbage intake rate by grazing ruminants is the canopy height. The objective of this study was therefore to characterise the effect of the canopy height on short-term herbage intake rate using *Sorghum bicolor* cv BR 501. as a reference. Two experiments were conducted at Research Station of the Federal University of Rio Grande do Sul, Brazil, between December 2009 and April 2010. The treatments in experiment 1 were used to determine the influence of the pre-grazing canopy height on the short-term herbage intake and consisted of six canopy heights (30, 40, 50, 60, 70 and 80 cm). The treatments in experiment 2 used the pre-grazing canopy height from experiment 1 that maximised the short-term herbage intake rate to evaluate the influence of the severity of grazing down (16, 33, 50, 67 and 84%) on the herbage intake. Both experiments used a completely randomised block design, with two replicates in experiment 1 and three replicates in experiment 2. Four heifers (24 ± 2 months and 306 ± 56.7 kg) were used in experiment 1. Three of these animals were used in experiment 2, which were then 26 ± 2 months and 339 ± 45.5 kg. The short-term herbage intake rate was measured by weighing the heifers pre-
…ing jaw movements
…Recorder. In both ex-
…opy height, the pre-grazing herbage mass and the vertical distribution of morphological components. In experiment 2, the post-grazing herbage mass was also measured. The results showed that the grazing canopy height that maximised the short-term herbage intake rate was approximately 50 cm. The grazing down protocol showed that the short-term herbage intake rate was constant until the depletion of 40% of the optimal pre-grazing canopy height. After this level of depletion, there was a marked reduction in the short-term herbage intake rate. The results show that the best target management height in a *Sorghum* cv. BR 501 pasture, allowing for high levels of the short-term herbage intake rate, is 50 cm. With intermittent stocking, this level should be considered as the pre-grazing canopy height, and the level of herbage depletion should not exceed 40%.

1. Introduction

In addition to grazing, the daily activities of an animal include a host of other essential activities that are essential to their survival (e.g., rumination, vigilance and idling). Therefore, management actions that provide an increase in the herbage intake rate, with the consequent reduction of the time necessary to achieve their daily nutrient requirement, is

* Corresponding author at: Grazing Ecology Research Group, Faculty of Agronomy, Federal University of Rio Grande do Sul, Av. Bento Gonçalves, 7712, Porto Alegre, RS 91540-000, Brazil. Tel.: +55 51 3308 7402.
E-mail address: lidianefnc@gmail.com (L. Fonseca).

1871-1413 © 2012 Elsevier B.V. Open access under the Elsevier OA license.
doi:10.1016/j.livsci.2012.02.003

essential for successful animal production (Carvalho et al., 2001).

Maintaining high rates of herbage intake requires the provisioning of appropriate sward structures. In the case of tropical swards, bulk density is one of the structural characteristics that determines the herbage intake rate by grazing animals (e.g., Brereton and McGilloway, 1998; Hodgson, 1985; Laca et al., 1992; Stobbs, 1975). Thus, the sward structure should be seen as a management target as it directly influences the herbage intake rate and, consequently, animal production (Gordon and Benvenutti, 2006; Hodgson, 1990). The canopy height is one of the structural sward variables that affect the short-term herbage intake rate (Carvalho et al., 2001; Forbes, 1988). For both continuous and intermittent stocking, the canopy height is an important management variable. With continuous stocking, the animals rarely take consecutive bites on the vertical stratum, while with intermittent stocking, the animals graze down the sward during grazing periods, changing the sward structure (Charnov, 1976). Severe grazing reduces the mass of green leaves and stems but increases the proportion of leaves to stems (Barret et al., 2001; Gregorini et al., 2011). As a consequence of herbage depletion, the foraging dynamics are altered and the short-term herbage intake is reduced (Barret et al., 2001; Baumont et al., 2004).

In this study, two experiments were performed based upon the hypothesis that different sward structures, formed by distinct canopy heights and levels of grazing down, influence the short-term herbage intake rate of cattle. The first experiment defined the ideal canopy height for grazing with short-term herbage intake maximisation to define the management target. The second experiment investigated the ideal level of herbage depletion using the same criterion. The experimental model is used to propose management targets with applications for intermittent and continuous stocking methods.

2. Material and methods

2.1. Experimental area

Two experiments were carried out at the Research Station of the Federal University of Rio Grande do Sul, Brazil (30º05′27″S, 51º40′18″W). An area of 5500 m^2 of *Sorghum bicolor* cv. BR 501 sown in December 2009 was used for experiment 1, and another area of 4820 m^2 of the same cultivar sown in February 2010 was used for experiment 2. Both pastures were no-tillage sod with a sown density of 33 kg ha^{-1}. The distance between rows was 0.17 m. Nitrogen, phosphorus and potassium were applied uniformly in the area twice: at sowing (20 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and K_2O ha^{-1}) and after 20 days (200 kg N ha^{-1}).

2.2. Treatments

Experiment 1 consisted of six pre-grazing canopy height treatments (30, 40, 50, 60, 70 and 80 cm) with two replicates in a randomised block design ($n=12$). Based upon the best pre-grazing canopy height set in experiment 1, the percentages of grazing down in experiment 2 were set at 16, 33, 50, 67 and 84%, equidistant among treatments. Experiment 2 had a randomised block design with three replicates ($n=15$). In both experiments, the blocking criterion was the time of day for the evaluation (morning and afternoon). The area for experiment 1 was scaled so that the canopy height remained relatively constant over the grazing period, such that the same sward structure was available for the animal both at the beginning and at the end of the grazing test. That is, the aim was for the sward structure, at the bite level, to remain constant over the entire grazing period. Twelve grazing tests of 45 min each were conducted between January and March 2010. The grazing period was defined as the minimum period of time necessary to detect weight fluctuations accurately with an electronic balance during the evaluation of the short-term herbage intake rate (adapted from Penning and Hooper, 1985).

For experiment 2, the paddocks were scaled so that the percentage of grazing down was achieved within approximately 45 min. To determine the area necessary for each treatment, a grazing test of 45 min was performed in an adjacent paddock with an area of 100 m^2. The canopy height was measured every 10 min during the grazing period, and calculations were based upon the percentage of grazing down in that defined 100 m^2 area to define the ideal area for each treatment. Fifteen grazing tests of 45 ± 5 min in April 2010 were performed. In both experiments, all tests were performed in the early morning and late afternoon.

2.3. Sward measurements

In both experiments, strata were cut every 10 cm using a 0.153 m^2 quadrat to determine the pre-grazing herbage mass. Five cuts were made in experiment 1 per experimental unit, whereas there were three such cuts for experiment 2 at ground level. In experiment 2, the post-grazing herbage mass was also sampled in 0.25 m^2 quadrats. The samples were separated into damaged herbage mass (e.g., pieces of broken or trampled plants) and intact herbage. All samples were separated into leaf lamina, stem and dead material and were then weighed. Next, they were dried at 55 °C for at least 72 h to determine the dry matter (DM) content. The total herbage mass was determined as the sum of the mass of each component (damaged or intact). To determine the canopy height, a *sward stick* was used to measure 200 points per experimental unit both pre- and post-grazing (Barthram, 1985).

2.4. Animal measurements

Four heifers were used in experiment 1 (24 ± 2 months and 306 ± 56.7 kg of live weight (LW)). Three of these animals were used in experiment 2 (26 ± 2 months old and 339 ± 45.5 kg LW). Approximately 30 days before each experiment, the animals were adapted to the experimental procedure and remained in an adjacent paddock with a *Sorghum* sward. In experiment 1, the animals were non-fasted before the grazing tests because such a method may increase the herbage intake rate (Gregorini et al., 2009b) and reduce diet selection (Newman et al., 1994). In experiment 2, the animals were fasted from solids for 5 h before each grazing test. Although it is known that hunger may change the bite dimensions and herbage intake rate (Gregorini et al., 2009b), the animals were fasted to ensure that they grazed down the total percentage intended. The fasting period was similar in all treatments, permitting valid comparisons.

Table 1
Pre-grazing sward height (cm), post-grazing sward height (cm), herbage mass (kg DM ha^{-1}), leaf mass (kg DM ha^{-1}) and stem mass (kg DM ha^{-1}) under different canopy heights grazed by beef heifers (means; n = 12).

	Canopy height (cm)						SE	*P value*
	30	40	50	60	70	80		
Pre-grazing sward height	31.3	41.3	50.7	59.2	70.8	82.4	1.8	<0.0001
Post-grazing sward height	31.1	39.5	49.6	58.9	70.0	81.6	1.8	<0.0001
Herbage mass	1281	1348	1852	3262	3760	4204	537.4	<0.0001
Leaf mass	872	878	1102	1772	1926	2135	223.8	<0.0001
Stems mass	409	460	740	1421	1795	2015	303.3	<0.0001

SE = standard error.
P = significance level.

Before the grazing tests, the animals were fitted with bags for the collection of faeces and urine and with an IGER Behaviour Recorder, which records the effective eating time and the number of grazing jaw movements (biting and non-biting). The data were analysed with the Graze software (Rutter et al., 1997). After the grazing test, the animals were kept in an adjacent area without water or food for 45 min to estimate insensible weight losses (evaporation of H_2O, loss and production of CO_2 and CH_4).

The short-term herbage intake rate was determined using the double weighting technique described by Penning and Hooper (1985). All weights (pre- and post-grazing and pre- and post-insensible weight losses) were taken on a balance with an accuracy of 10 g. The short-term herbage intake rate was calculated by the equation:

$$\mathrm{STIR} = \frac{(W2\text{–}W1)}{t2\text{–}t1} + \frac{(W3\text{–}W4)}{t4\text{–}t3} \times \frac{(t2\text{–}t1)}{ET}.$$

Where: STIR = short-term herbage intake rate; W1 and W2 = animal's weight pre- and post-grazing; t1 and t2 = time pre- and post-grazing; W3 and W4 = animal's weight pre- and post-insensible weight losses; t3 and t4 = time pre- and post-insensible weight losses; and ET = effective eating time.

The short-term herbage intake rate was corrected for the DM content in both experiments. The DM content was estimated by cutting four samples from each experimental unit, two pre- and two post-grazing. In experiment 1, the samples were harvested in the superior stratum of the sward because at this location, there is a 50% proportional relationship between the herbage removed with each bite and the canopy height (Cangiano et al., 2002; Gonçalves et al., 2009; Laca et al., 1992). For experiment 2, the samples were collected until the canopy height reached the percentage of grazing down for each treatment.

2.5. Statistical analysis

Data were analysed using linear regression ($y_{ij} = a + bx + \epsilon_{ij}$), quadratic ($y_{ij} = a + bx + cx^2 + \epsilon_{ij}$) and segmented equation (broken line, $y_{ij} = L + U^*[(R<x)\ (R\text{-}x)] + \epsilon_{ij}$) using JMP software version 8 (SAS Institute Inc., Cary, NC, USA). The equations were compared using the coefficient of determination (R^2), since significant at 5% of significance level. All variables showed normal distribution (tested by Kolmogorov–Smirnov test; $P > 0.05$). In all of the analyses, the animal test group was considered to be an experimental unit.

3. Results

3.1. Experiment 1

The DM content did not differ among the experimental units, with an overall mean of 27 ± 0.04% (P = 0.5801). The actual canopy height increased linearly with the treatments, both pre- and post-grazing (Table 1). Inside each paddock, the post-grazing canopy height did not differ by more than 5% from the pre-grazing canopy height, ensuring that all bites taken throughout the grazing test were taken in a similar sward structure, which was essential to studying the proposed hypothesis.

The herbage mass, leaf mass and stem mass were linearly correlated with the canopy height ($P < 0.0001$). The mean proportion of the leaf lamina and stem components is shown in Fig. 1. In canopy heights up to 50 cm, the percentage of leaf laminas decreased while the percentage of stems increased. The percentage of these morphological components stabilised above 50 cm.

The bulk densities of the morphological components are presented in Fig. 2. Independent of the treatment, a higher sward bulk density was observed in the lower strata due to increased proportions of stems. The short-term herbage intake rate was non-linearly related to the canopy heights studied (i.e., an equation with a broken line; $P = 0.0007$) (Fig. 3), indicating that the maximum values are achieved

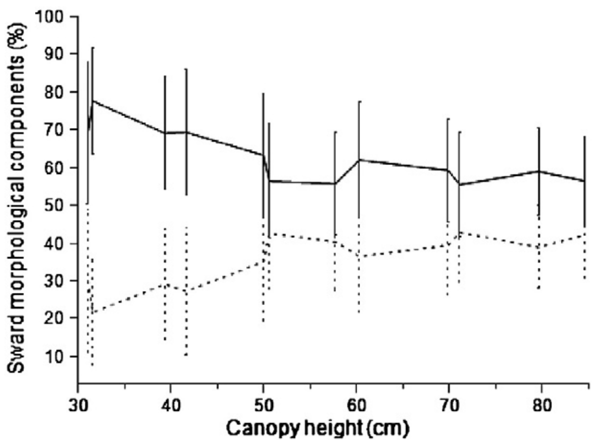

Fig. 1. Sward morphological components (%) of *Sorghum bicolor* sward grazed by beef heifers under different canopy heights (leaf laminas _____ and stems _ _ _ _).

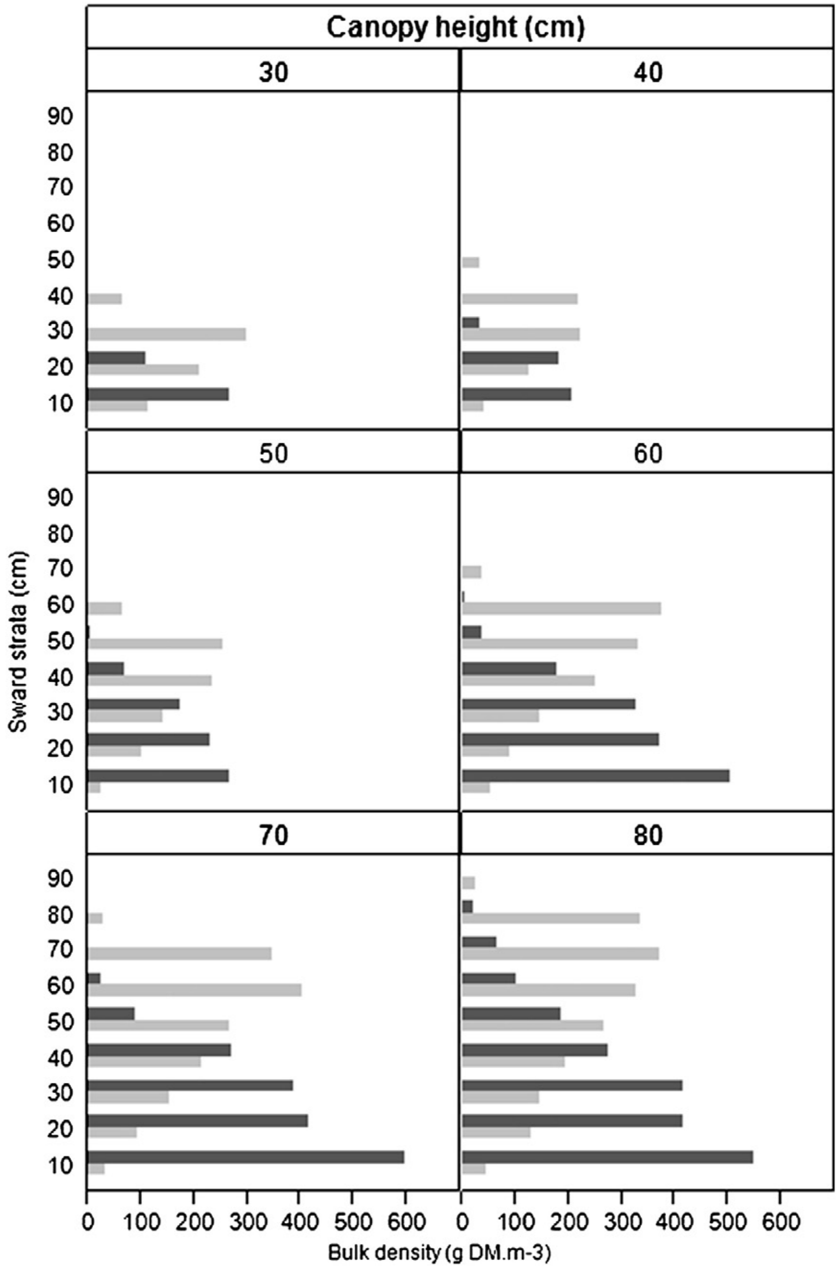

Fig. 2. Bulk density of the morphological components on the sward strata of *Sorghum bicolor* sward grazed by beef heifers under different canopy heights (leaf laminas and stems).

in canopy heights of up to 50 cm, but at 60 cm and above, the short-term herbage intake rate of heifers is reduced.

3.2. Experiment 2

There were no differences in the DM content among treatments, with a mean of 24 ± 0.04% ($P = 0.3932$). All of the sward characteristics were similar ($P > 0.05$) among the treatments prior to grazing (Table 2). As is necessary to test the main hypothesis, the post-grazing canopy heights showed a decreasing linear relationship with the level of grazing down imposed ($y = 51.89 - 51.6x$; $R^2 = 0.99$; $P < 0.0001$). The same response was observed for the post-grazing leaf mass ($y = 694.0 - 8.9x$; $R^2 = 0.89$; $P < 0.0001$) and total post-grazing herbage mass ($y = 1968.47 - 1164.26x$; $R^2 = 0.57$; $P = 0.0011$). Alternatively, the post-grazing damaged herbage mass increased with increases in the grazing down levels ($y = 4.39 + 615.35x$; $R^2 = 0.64$; $P = 0.0372$). The mass of the stems did not change until the grazing down level reached 50%, at which point it showed a linear decline ($y = 538.97 + 11.97(50 - x)$ if $x > 50$; constant value of 538.97 if $x < 50$; $R^2 = 0.47$; $P = 0.0314$). As shown in Fig. 4, the short-term herbage intake rate of the heifers

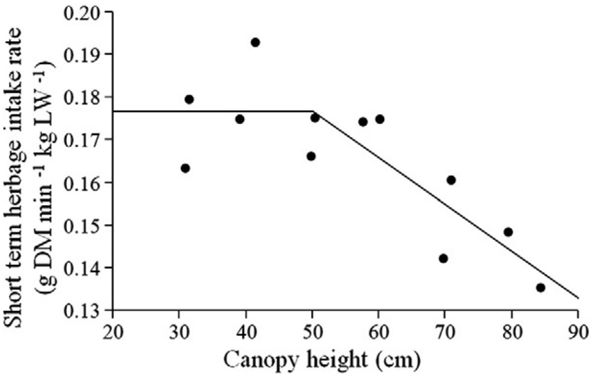

Fig. 3. Short-term intake rate of beef heifers grazing a *Sorghum bicolor* sward under different canopy heights ($y=0.176+0.001(50-x)$, if $x>50$, and $y=0.176$ if $x<50$; $R^2=0.70$; $P=0.0007$; SE = 0.00096).

remained constant until the grazing down level reached 40%, after which it showed a linear reduction ($P<0.0001$).

4. Discussion

The aim of this study was to find an optimal sward structure for *Sorghum* using the canopy height as the best representative variable that could lead to management targets. The criterion for the ideal sward structure was based upon the maximisation of the short-term herbage intake rate of beef heifers.

4.1. Ideal sward structure for grazing: experiment 1

The basic assumption that the post-grazing canopy height should not be less than 95% of the pre-grazing canopy height ensured that changes observed in the short-term herbage intake rate were responses to the pre-grazing vertical structure of the sward. As grazing proceeds, vertical and horizontal constraints alter the ingestive behaviour of the animal and the short-term herbage intake rate (Burns and Sollenberger, 2002); therefore, structural changes had no influence during the grazing period. In this context, the short-term herbage intake rate of the animals was optimised until the canopy height was 50 cm, reaching maximum values of approximately 0.17 g of DM kg LW min^{-1} (54 g DM min^{-1}). This value was similar to those found in other experiments, such as those performed by Chilibroste et al. (1997) with perennial ryegrass and Utsumi et al. (2009) with fescue and alfalfa.

According to Carvalho et al. (2001), grazing management is the art of creating and manipulating sward structures to optimise the prehension process of the animal. The ideal canopy height of up to 50 cm presented here should be a management goal to maximise the short-term herbage intake rate of animals in *Sorghum* with either intermittent or continuous stocking. In addition because grazing at low canopy heights can limit the regrowth of plants, the 50 cm optimum canopy height for grazing is defined as the pre-grazing canopy height with intermittent stocking. With continuous stocking, the optimum canopy height is defined as the canopy height further explored by the animals throughout the grazing period.

The vertical distribution of sward components influences the intake processes (Carrère et al., 2001; Demment and Laca, 1993; Stuth et al., 1987; Ungar, 1996) either in relation to the absolute canopy height (Armstrong et al., 1995), the leaf bulk density (Demment et al., 1995; Flores et al., 1993) or the leaf accessibility (Gregorini et al., 2009a). At canopy heights lower than 50 cm, the proportion of stems increased while the proportion of leaf laminas decreased, stabilising at approximately 60% leaf laminas and 40% stems (Fig. 1). Thus, part of the decrease in the short-term herbage intake rate at high canopy heights can be attributed to the greater proportion of stems. In addition, the herbage bulk density decreased in the upper strata of swards in treatments with large canopy heights (60, 70 or 80 cm), which influenced the prehension of herbage differently when the animals grazed lower canopy heights (30, 40 or 50 cm) (Fig. 2). Finally, the structure of the smaller canopy swards had a herbage mass with a higher proportion of leaves (Fig. 1), while larger canopy heights (greater than 60 cm) had a lower proportion of leaves (Fig. 1) and a lower herbage bulk density (Fig. 2), which caused a marked reduction in the short-term herbage intake rate of the heifers (Fig. 3).

Table 2
Actual grazing down level (%), pre-grazing sward height (cm), post-grazing sward height (cm), pre-grazing herbage mass (kg DM ha^{-1}), post-grazing intact herbage mass (kg DM ha^{-1}), post-grazing damaged herbage mass (kg DM ha^{-1}), post-grazing total herbage mass (kg DM ha^{-1}), pre and post-grazing leaf mass (kg DM ha^{-1}) and pre and post-grazing stem mass (kg DM ha^{-1}) of *Sorghum* cv 501 swards under grazing down levels grazed by beef heifers (means; n = 15).

	(Grazing down level; %)					SE	*P value*
	16	33	50	67	84		
Actual grazing down level	16.7	35.9	52.3	62.9	77.1	–	–
Pre-grazing sward height	52.1	51.7	53.2	51.8	52.5	1.10	0.4405
Post-grazing sward height	43.4	33.0	25.4	19.2	11.6	0.61	<0.0001
Pre-grazing herbage mass	2706	2964	2530	2837	2673	576	0.9738
Post-grazing intact herbage mass	1654	1117	1089	553	426	188	<0.0001
Post-grazing damaged herbage mass	151	262	403	774	414	207	0.0372
Post-grazing total herbage mass	1805	1379	1492	1328	840	228	0.0011
Pre-grazing leaf mass	1568	1830	1571	1756	1584	376	0.9249
Post-grazing leaf mass	549	388	210	29	41	75	<0.0001
Pre-grazing stem mass	1137	1134	959	1081	1088	221	0.8055
post-grazing stem mass	494	545	533	328	254	191	0.0314

SE = standard error.
P = significance level.

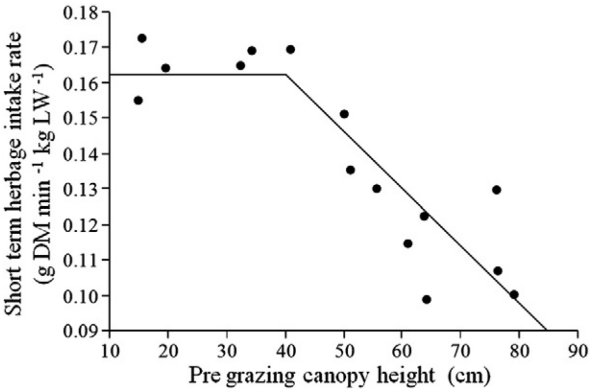

Fig. 4. Short-term intake rate by beef heifers grazing a *Sorghum bicolor* sward under grazing down levels ($y=0.16+0.001(40-x)$, if $x>40$, and $y=0.16$ if $x<40$; $R^2=0.81$; $P<0.0001$; SE $=0.014$).

4.2. Depletion without depression in short term herbage intake rate: experiment 2

More than other methods, the intermittent stocking method dictates where, when and what the animals graze. To achieve success with this grazing method, the manager should provide adequate sward structures to the animals that maximise their short-term herbage intake rate. Therefore, the grazing should begin with a high short-term herbage intake rate; for *Sorghum*, the canopy height should be managed at 50 cm. Working with intermittent stocking, Brereton et al. (2005) found increases in the initial intake rate that were maximised after the superior stratum had been removed by the animals. That is, the initial canopy height did not maximise the herbage intake rate. Instead, the animals achieved optimum intake only when they removed 80% of the superior stratum of the sward (Ungar, 1998).

As shown in Table 2, there was a linear reduction in the post-grazing mass of stems after the grazing down level reached 50%. This result suggests that animals only graze these components when they access lower grazing horizons, i.e., when the leaf laminas become reduced and are damaged by trampling.

The short-term herbage intake rates in the lower grazing down treatments were high (0.16 g DM kg LW min^{-1} or 54 g DM min^{-1}) compared to the higher grazing down treatments (0.10 g DM kg LW min^{-1} or 37 g DM min^{-1}). This response is in concordance with the results of Drescher et al. (2006), who observed approximately 51 g DM min^{-1} for heifers grazing *Panicum maximum* with 100% leaves, and corresponds to the smallest level of grazing down. Alternatively, Drescher et al. (2006) observed approximately 9 g DM min^{-1} with 25% leaves, which corresponds to the higher grazing down treatments of the present study. The difference observed in the values of the higher grazing down levels is probably linked to the high percentage of leaves at the beginning of the study, with a high short-term herbage intake rate, and its reduction over the course of the grazing down period, resulting in the decrease in the short-term herbage intake rate. Thus, the values observed in the present study correspond to an average between high and low proportions of leaves. Such small short-term herbage intake rates would likely increase the animal's daily grazing time to compensate for the reduction in herbage intake (Allden and Whittaker, 1970).

Assuming that the intermittent stocking paddock is a *patch* (see definition of Illius and Gordon, 1999), Optimal Foraging Theory (Charnov, 1976) would predict that the optimal use of the paddock by the animal would occur only when the short-term herbage intake rate remained constant. When the short-term herbage intake rate decreased, the animal, if it had a choice, would move to a new *patch* (Bailey et al., 1996). Following this analogy and assuming that 50 cm is the ideal canopy height for *Sorghum*, the grazing down tests showed that the maximisation of the short-term herbage intake rates could be maintained with grazing down because they did not exceed the limit of 40% of pre-grazing canopy height (Fig. 4). Beginning at grazing down levels of 40%, the animals access the grazing horizon with restricted accessibility to leaves (Table 2; Gregorini et al., 2011). This condition induced a gradual decrease of the short-term herbage intake rate until the end of the period (Fig. 4). Similarly, Searle et al. (2005) observed exponential and broken-line responses of the herbage intake rate to the time that the animals remained in the *patch*.

Horizontal changes in the availability and accessibility of green leaves at the bite horizon (Table 2) constraints the foraging behaviour (Gregorini et al., 2011) and herbage intake rate (Fig. 4). Benvenutti et al. (2008) similarly observed that the increase in the proportion of stems in the lower stratum of the sward did not allow for a high short-term herbage intake rate.

5. Conclusion

To maximise the short-term herbage intake rate of beef heifers, management targets should permit animals to graze swards of *Sorghum* at canopy heights of approximately 50 cm. Likewise, with intermittent stocking, management targets should prioritise herbage depletion without depressing the sward structure. Therefore, *Sorghum* swards should be managed with grazing down permitted until 40% of the pre-grazing canopy height of approximately 50 cm is reached, which allows for the maintenance of high short-term herbage intake rates.

Conflict of interest statement

The interest of this study was only scientific in order to generate a target management of the pasture of *S. bicolor* that allows increased production. So, all authors state that there are no financial and personal conflicts of interest that could have inappropriately influenced their work.

Acknowledgments

We thank the International Cooperation of Associated Centers of Post-graduation (CAPES-SPU), which provided the interaction between students and professors of Brazil and Argentina.

References

Allden, A.G., Whittaker, I.A. McD, 1970. The determinants of herbage intake by grazing sheep: the interrelationship of factors influencing herbage intake and availability. Aust. J. Agric. Res. 21, 755–766.

Armstrong, R.H., Robertson, E., Hunter, E.A., 1995. The effect of sward height and its direction of change on herbage intake, diet selection and performance on weaned lambs grazing ryegrass swards. Grass Forage Sci. 50, 389–398.

Bailey, D.W., Gross, J.E., Laca, E.A., Rittenhouse, L.R., Coughenour, M.B., Swift, D.M., Sims, P.L., 1996. Mechanisms that result in large herbivore grazing distribution patterns. J. Range Manage. 49, 386–400.

Barret, P.B., Laidlaw, A.S., Mayne, C.S., Christie, H., 2001. Pattern of herbage intake rate and bite dimensions of rotationally grazed dairy cows as sward height declines. Grass Forage Sci. 56, 362–373.

Barthram, G.T., 1985. Experimental techniques: the HFRO sward stick. In: Alcock, M.M. (Ed.), Biennial Report of the Hill Farming Research Organization. Hill Farming Research Organization, Midlothian, pp. 29–30.

Baumont, R., Cohen-Salmon, D., Prache, S., Sauvant, D., 2004. A mechanistic model of intake and grazing behaviour in sheep integrating sward architecture and animal decisions. Anim. Feed Sci. Technol. 112, 5–28.

Benvenutti, M.A., Gordon, I.J., Poppi, D.P., 2008. The effects of stem density of tropical swards and age of grazing cattle on their foraging behaviour. Grass Forage Sci. 63, 1–8.

Brereton, A.J., McGilloway, D.A., 1998. Sward factors and herbage intake. Pasture Ecology and Animal Intake. Proceedings of a Workshop Held in Dublin, September 1996: Occasional Publication, n. 3, pp. 144–162 (Dublin).

Brereton, A.J., Holden, N.M., McGilloway, D.A., Carton, O.T., 2005. A model describing the utilization of herbage by cattle in a rotational grazing system. Grass Forage Sci. 60, 367–384.

Burns, J.C., Sollenberger, L.E., 2002. Grazing behavior of ruminants and daily performance from warm-season grasses. Crop. Sci. 42, 873–881.

Cangiano, C.A., Galli, J.R., Pece, M.A., Dichio, L., Rozsypalek, S.H., 2002. Effect of live weight and pasture height on cattle bite dimensions during progressive defoliation. Aust. J. Agric. Res. 53, 541–549.

Carrère, P., Louault, F., Carvalho, P.C.F., Lafarge, M., Soussana, J.F., 2001. How does the vertical and horizontal structure of a perennial ryegrass and white clover sward influence grazing? Grass Forage Sci. 56, 118–130.

Carvalho, P.C.F., Ribeiro Filho, H.M.N., Poli, C.H.E.C., Delagarde, R., 2001. The importance of sward structure on intake and diet selection by the grazing animal. Proceedings of the Annual Meeting of the Brazilian Society of Animal Science: Animal Production in View of the Brazilian, Piracicaba, pp. 853–871 (in Portuguese).

Charnov, E.L., 1976. Optimal foraging: the marginal value theorem. Theor. Popul. Biol. 9, 129–136.

Chilibroste, P., Tamminga, S., Boer, H., 1997. Effects of length of grazing session, rumen fill and starvation time before grazing on dry-matter intake, ingestive behaviour and dry-matter rumen pool sizes of grazing lactating dairy cows. Grass Forage Sci. 52, 249–257.

Demment, M.W., Laca, E.A., 1993. The grazing ruminant: models and experimental techniques to relate sward structure and intake. Proceedings of the World Conference on Animal Production, Edmonton, pp. 439–460.

Demment, M.W., Peyraud, J.L., Laca, E.A., 1995. Herbage intake at grazing: a modelling approach. In: Journet, M., Grenet, E., Farce, M.H., Thèriez, M., Demarquilly, C. (Eds.), Recent Developments in the Nutrition of Herbivores, Proceedings of the IVth International Symposium on the Nutrition of Herbivores. INRA Editions, Paris, pp. 121–141.

Drescher, M., Heitkönig, I.M.A., Raats, J.G., Prins, H.H.T., 2006. The role of grass stems as structural foraging deterrents and their effects on the foraging behaviour of cattle. Appl. Anim. Behav. Sci. 101, 10–26.

Flores, E.R., Laca, E.A., Griggs, T.C., Demment, M.W., 1993. Sward height and vertical morphological differentiation determine cattle bite dimensions. Agron. J. 85, 527–532.

Forbes, T.D.A., 1988. Researching the plant–animal interface: the investigation of ingestive behavior in grazing animal. J. Anim. Sci. 66, 2369–2379.

Gonçalves, E.N., Carvalho, P.C.F., Kunrath, T.R., Carassai, I.J., Bremm, C., Fisher, V., 2009. Plant-animal relationships in pastoral heterogeneous environment: process of herbage intake. Bras. J. Anim. Sci. 38, 1655–1662 (in Portuguese).

Gordon, I.J., Benvenutti, M., 2006. Food in 3D: how ruminant livestock interact with sown sward architecture at bite scale. Feeding in Domestic Vertebrates: From Structure to Behavior. CAB International.

Gregorini, P., Gunter, S.A., Beck, P.A., Caldwell, J., Bowman, M.T., Coblentz, W.K., 2009a. Short-term foraging dynamics of cattle grazing swards with different canopy structure. J. Anim. Sci. 87, 3817–3824.

Gregorini, P., Soder, K.J., Kensinger, R.S., 2009b. Effect of rumen fill on foraging behavior, intake rate, and plasma ghrelin, serum insulin and glucose levels of cattle grazing a vegetative micro-sward. J. Dairy Sci. 92, 2095–2105.

Gregorini, P., Gunter, S.A., Bowman, M.T., Caldwell, J.D., Masino, C.A., Coblentz, W.K., Beck, P.A., 2011. Effect of herbage depletion on short-term foraging dynamics and diet quality of steers grazing wheat pastures. J. Anim. Sci. 20, 60–66.

Hodgson, J., 1985. The control of herbage intake in the grazing ruminant. Proc. Nutr. Soc. 44, 339–346.

Hodgson, J., 1990. Grazing Management. Science into Practice, Hong Kong.

Illius, A.W., Gordon, I.J., 1999. The physiological ecology of mammalian herbivory. In: Jung, H.J.G., Fahey Jr., G.C. (Eds.), Nutritional Ecology of Herbivores. American Society of Animal Science, Savoy, pp. 71–96.

Laca, E.A., Ungar, E.D., Demment, M.W., 1992. Effects of sward height and bulk density on bite dimensions of cattle grazing homogenous swards. Grass Forage Sci. 47, 91–102.

Newman, J., Penning, P., Parsons, A., Harvey, A., Orr, R., 1994. Fasting affects intake behavior and diet preference of grazing sheep. Anim. Behav. 47, 185–193.

Penning, P.D., Hooper, G.E.N., 1985. An evaluation of the use of short-term weight changes in grazing sheep for estimating herbage intake. Grass Forage Sci. 40, 79–84.

Rutter, S.M., Champion, R.A., Penning, P.D., 1997. An automatic system to record foraging behaviour in free-ranging ruminants. Appl. Anim. Behav. Sci. 54, 185–195.

Searle, K.R., Vandervelde, T., Hobbs, N.T., Shipley, L.A., 2005. Gain functions for large herbivores: tests of alternative models. J. Anim. Ecol. 74, 181–189.

Stobbs, T.H., 1975. Factors limiting the nutritional value of grazed tropical pastures for beef and milk production. Trop. Gras. 9, 141–149.

Stuth, J.W., Brown, J.R., Olson, P.D., Araujo, M.R., Aljoe, H.D., 1987. Effects of stocking rate on critical plant-animal interactions in a rotationally grazed Schizachyrium-Paspalum savannah. In: Horn, F.P., Hodgson, J., Mott, J.J., Brougham, R.W. (Eds.), Grazing Land Research at the Plant–Animal Interface. Winrock International Institute, Morrilton, AR, pp. 115–139 (pp. 115–139).

Ungar, E.D., 1996. Ingestive behaviour. In: Hodgson, J., Illius, A. (Eds.), The Ecology and Management of Grazing Systems. CAB International, Wallingford, pp. 185–218.

Ungar, E.D., 1998. Changes in bite area and bite depth during patch depletion by cattle. In: Gibb, M.J. (Ed.), Proceedings of Xth European Intake Workshop on Techniques for Investigating Intake and Ingestive Behaviour by Farm Animals. IGER, North Wyke, pp. 81–82.

Utsumi, S.A., Cangiano, C.A., Galli, J.R., McEachern, M.B., Demment, M.W., Laca, E.A., 2009. Resource heterogeneity and foraging behaviour of cattle across spatial scales. BMC Ecol. 9, 9.